Non-Rod Experiments for Improving Atomization Technology and U_3Si_2 Powder Fabrication at KAERI

Jonghwan Kim*, Jaedong Lee, Jungmin Park, Yongjin Jeong
Research Reactor Fuel Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea
**Corresponding author: kjh0272@kaeri.re.kr*

1. Introduction

Korea Atomic Energy Research Institute(KAERI) developed the atomization technology for U-Si powder for HANARO research reactor fuel and successfully fabricated the atomized U-Si powder in 1991[1]. Since then, KAERI has been developing atomization technology presented in Fig. 1.

Atomized powder is known for its high purity with fewer defects and high production yield rates, because the atomization process is much simpler than the conventional crushing methods. Compared to the conventional pulverized powder fabricated by the crushing methods, the atomized powder, which is spherical in shape, has advantages such as high uranium loading capability, various U alloy compositions, and homogenous particle distribution[2].

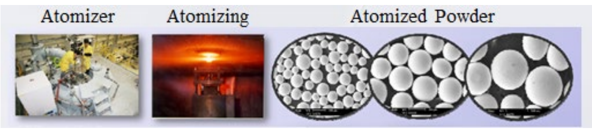

Fig. 1. KAERI centrifugal atomization technology [3]

Coating agents are applied between the pouring rod and the ceramic crucible shown in Fig. 2 (Extracting Part of the Drawing) to prevent the molten U alloy from leaking. When the target temperature is reached, the pouring rod is lifted so that the molten U alloy flows down through the nozzle of the ceramic crucible by gravity. The molten U alloy then reaches a rotating disk and is sprayed as droplets. These droplets cool rapidly and form fine spherical particles with diameters less than 150 ㎛.

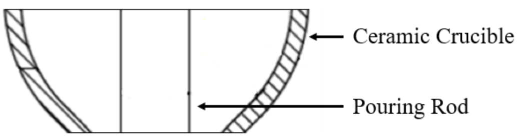

Fig. 2. Ceramic Crucible and Pouring Rod

For U_3Si_2 atomization, the molten U_3Si_2 alloy must be heated to approximately 2000°C as the target temperature. This severe thermal condition can cause significant damage on the components such as the pouring rod and the coating agents, leading to low yield rates or failures.[4]

Under those U_3Si_2 atomization process conditions, leak failures related to high temperatures near 2000°C of the molten U_3Si_2 alloy occurred, causing the molten U_3Si_2 alloy to dribble down onto the disk without lifting the rod. To address this issue, the pouring rod was removed so that coating agents were no longer needed between the rod and the crucible.

The properties of the coating agents, which indicated leak failures occurring near 2000°C, were applied to the nozzle of the crucible instead. The goal of this non-rod experiment was to check and ensure that the molten U_3Si_2 alloy flowed down onto the disk automatically without the rod after reaching 2000°C.

2. Methods and Result

The non-rod experiment's conditions and process parameters could not be fully described due to the confidentiality for KAERI's atomization technology, which has been designated as a National Core Technology by the Ministry of Trade, Industry and Energy in Korea.

The non-rod experiments were conducted four times using two different types of coating methods. The same method was applied to each pair of experiments; the same process conditions for loadings and temperatures were applied throughout all experiments, as detailed in Table I.

Table I: Non-rod Experiment's Conditions for U_3Si_2 Atomized Powder

Batch Name	Applying Coating Agents on Nozzle	Loading (g)	Temp. (°C)
C2405	1st Method	<500	<2100
C2406	1st Method	<500	<2100
C2407	2nd Method	<500	<2100
C2408	2nd Method	<500	<2100

In the first experiment (C2405 batch), the primary leak occurred at 1150℃ when U began to melt and started to form an alloy with Si. A secondary leak occurred at 1900℃, which appeared to be related to instability in the coating agents. At 2050℃, leakage of the entire molten U_3Si_2 alloy began, but instead of trickling at the center of the disk, the molten alloy trickled onto the edges. As shown in Figure 3, this resulted in an unstable powder spraying process and some molten alloy leaked through cracks in the exterior of the ceramic crucible, rather than through the nozzle, and was found to have adhered to the graphite components. After the sieving process, the yield for U_3Si_2 powder with diameters less than 150 ㎛ was 15.8%.

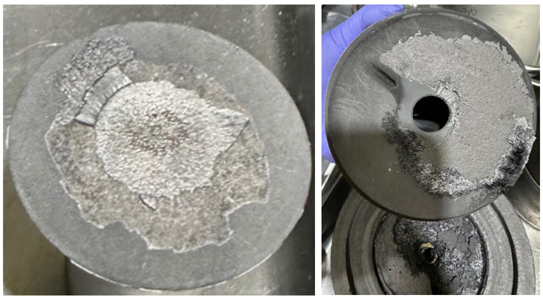

Fig. 3. Atomization Component Parts after first experiment (C2405 batch) : Disk(Left), Carbon Parts(Right)

In the second experiment (C2406 batch), the same process conditions as the first experiment were repeated. At 1150℃, where U and Si started to react chemically, the leakage of the entire molten U_3Si_2 alloy occurred. Since there were no traces of the molten alloy on the exterior of the ceramic crucible or near the graphite components, it suggested that the molten U_3Si_2 alloy leaked only through the nozzle and solidified in the ingot as shown in Figure 4. The leakage problem that occurred early stage before reaching 2000°C was caused by the failure to apply the coating agents properly, resulting in 0% yield rate of U_3Si_2 powder.

Fig. 4. Atomization Component Parts after second experiment (C2406 batch) : Disk and Ingot(Left), Carbon Parts(Right)

In the third experiment (C2407 batch), the issues observed in the previous experiments, such as leaks at 1150℃ and 1900℃, were resolved. Consequently, the temperature was successfully increased to 2050℃ without any leaks. At 2050℃, the molten U_3Si_2 alloy automatically leaked and trickled out onto the disk. Subsequently, Ar gas was inserted into the chamber, and the disk was rotated simultaneously to obtain the normal U_3Si_2 powder. There were no unusual findings in the ceramic crucible, but the molten alloy fell to the periphery of the disk instead of the center. This led to an unstable powder spraying process, resulting in U_3Si_2 powder adhering to surrounding components and causing loss as shown in Figure 5. The yield for U_3Si_2 powder with diameters less than 150 ㎛ was 29.4%, which represents an improvement compared to the first experiment (C2405 batch).

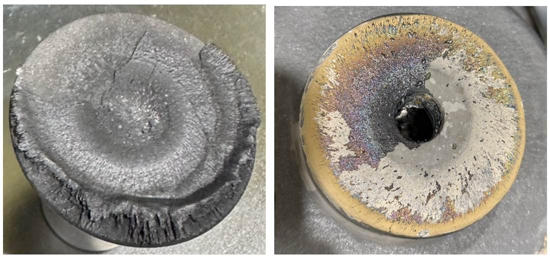

Fig. 5. Atomization Component Parts after third experiment (C2407 batch) : Disk(Left), Carbon Parts(Right)

Fig. 6. U_3Si_2 powder of C2407 batch before sieving

In the fourth experiment (C2408 batch), it was confirmed that there were no leaks from the molten alloy up to 2050℃. For safety reasons, this experiment was terminated without proceeding with any further spraying and powder fabrication processes. As shown in Figure 7, the entire U_3Si_2 alloy ingot remained intact in the ceramic crucible.

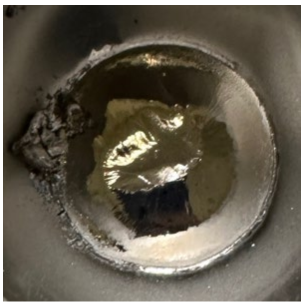

Fig. 7. U_3Si_2 alloy ingot in the ceramic crucible after forth experiment (C2408 batch)

The results of the yield rate for U_3Si_2 powder with diameters less than 150 ㎛ over the experiments (C2405~C2408 batches) were summarized in Table II.

Table II: Non-rod Experiment's yield rate for U_3Si_2 powder with diameters less than 150 ㎛

Batch Name	Yield rate (%)	Remark
C2405	15.8	-
C2406	-	Failure related to applying coating agents
C2407	29.4	-
C2408	-	Stopped on purpose before spraying

3. Conclusion

The experiments demonstrated that by applying a specific coating method, it is possible to control automatic outflow and fine trickling of the molten U_3Si_2 alloy through the ceramic crucible's nozzle without using the pouring rod at high temperatures (near 2000°C). However, to fully implement the advanced non-rod atomization technology, further experiments are needed to address the following issues:

1. Increase the loading capacity to more than 3 kg.
2. Adjust the control of the molten U_3Si_2 alloy to fall at the center of the disk to ensure proper spraying.
3. Improve the yield rate for U_3Si_2 powder with diameters less than 150 ㎛ to over 90%.

Once these improvements are completed and applied to the atomization process, many problems caused by the pouring rod will be resolved. These achievements are expected to significantly contribute to the stable fabrication for atomized U_3Si_2 powder at KAERI.

REFERENCES

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